Geological and Chromophoric Mechanisms Governing the Natural Formation of Fancy Colored Diamonds

Author: Independent Gemological Research

Publication Target: Academia.edu (Academic Working Paper / Monograph)

Keywords: Natural Colored Diamond, Natural Diamond, Antique Diamond, Chromophores, Gemology, Mantle Geodynamics

Abstract

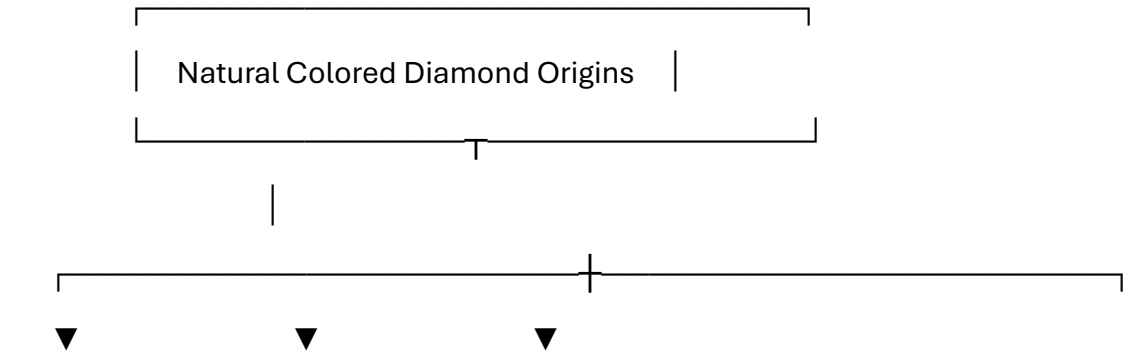
While pure diamonds consist strictly of sp^3-hybridized carbon arranged in a face-centered cubic lattice, fewer than 0.1% of all gem-quality specimens exhibit vivid colorations. This paper examines the natural phenomena responsible for producing a **natural colored diamond**, including trace element substitution, structural plastic deformation, natural radiation exposure, and aggregate micro-inclusions. Additionally, we discuss historical cutting techniques seen in the **antique diamond**, analyzing how vintage optical geometries interact with sub-surface light reflection in fancy color stones.

1. Introduction & Mantle Environment

Diamonds crystallize within the subcratonic lithospheric mantle at depths ranging from 140 to 250 kilometers, where temperatures exceed 900°C to 1300°C and pressures range between 4.5 and 6.0 GPa. A standard **natural diamond** appears colorless when light traverses its lattice without selective wavelength absorption.

However, perturbations during mantle residence—or during transport via deep-seated kimberlite and lamproite magma eruptions—can introduce structural anomalies or trace chemical impurities. These anomalies, known as *chromophores*, alter the diamond's energy band structure, causing selective absorption in the visible light spectrum (380-750 nm).

2. Primary Chromophores and Color Mechanisms



2.1 Trace Element Substitution

- **Nitrogen (N):** The most common impurity. Nitrogen atoms substitute for carbon in the crystal lattice.

    - *Type Ia:* Nitrogen forms aggregate clusters (A and B centers), absorbing ultraviolet and violet wavelengths to yield a classic yellow cast.
    - *Type Ib:* Isolated single nitrogen atoms cause intense absorption in the blue spectrum, producing vivid canary yellow and orange hues.
- **Boron (B):** Defines *Type IIb* diamonds. Substituting fewer than 1 part per million (ppm) of boron for carbon creates an uncompensated acceptor state, causing absorption of red/near-infrared light and resulting in a blue or greyish-blue color.

2.2 Plastic Deformation and Shear Stress

- **Pink, Red, and Brown Diamonds:** Unlike yellow or blue gems, pink and red hues do not stem from trace chemical impurities. Instead, extreme directional pressure during tectonic activity forces layers of carbon atoms to shift along the {111\} glide plane. This physical strain distorts the crystal lattice—a process known as *plastic deformation*—creating narrow glide zones (glide planes) that absorb green light and transmit rich pink and red tones.

2.3 Natural Irradiation

- **Green Diamonds:** As kimberlite pipes bring diamonds closer to the Earth's crust, proximity to radioactive minerals (such as uranium or thorium) exposes the lattice to alpha, beta, and gamma radiation. This knocks carbon atoms out of position, creating atomic vacancies (known as the GR1 color center) that absorb red light and impart a natural green surface hue.

3. Historical Optics: Chromophoric Display in the Antique Diamond

Prior to modern precision cutting protocols, lapidaries crafted the **antique diamond**—predominantly Old Mine, Old European, and Rose cuts—by hand under ambient lighting.

From an optical perspective, antique cuts feature deeper pavilions, smaller table facets, and open culets. When applied to fancy color rough, these proportions lengthen the internal light path (*path length optimization*). The longer light rays bounce inside the gemstone, the more pronounced the selective wavelength absorption becomes, often intensifying the perceived body color of a light yellow or pink stone compared to modern brilliant cuts.

4. Conclusion & Authentication Standards

Understanding the geological origin of color allows researchers to differentiate between untreated earth-mined gems and lab-enhanced specimens. Modern verification relies on photoluminescence (PL) spectroscopy, Fourier-transform infrared (FTIR) spectroscopy, and color grading protocols established by institutions such as the Gemological Institute of America (GIA).

References & Further Reading

- Breeding, C. M., & Shirey, S. B. (2006). *The classification of diamonds*. Gems & Gemology, 42(3), 206-211.
- Shigley, J. E., & Fritsch, E. (1990). *Analysis of color in natural fancy-color diamonds*. Gems & Gemology, 26(1), 4-27.
- Harlow, G. E. (1998). *The Nature of Diamonds*. Cambridge University Press / American Museum of Natural History.